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14. ABSTRACT Experiments with human subjects explored how auditory attention operates. Specifically, the experiments investigated 1) the hypothesis that room reverberation interferes with selective attention, 2) whether selective attention to an ongoing target improves with time when the target has a contiguous feature distinguishing it from competing sources, and 3) how visual cues help direct selective auditory attention through behavioral measures and computational modeling. Results demonstrate that 1) selective attention is adversely affected by room reverberation, 2) continuity of task-irrelevant sound features strongly enhances the ability to maintain attention on a stream based on some other, orthogonal feature, and 3) visual cues can be used to direct selective auditory attention.					
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Focusing, sustaining, and switching attention

A. Scientific and Technical Objectives

Acoustic information is conveyed by changes in sound over time, requiring listeners to *sustain* attention to understand acoustic signals. Moreover, sounds start and stop, requiring attention *switching*. To predict how well humans can communicate in complex acoustic scenes, we must understand the dynamics of focusing, sustaining, and switching selective auditory attention. However, most past work has ignored attentional dynamics. This project used perceptual and computational experiments to explore the dynamics of selective attention.

Aim 1. Influence of room acoustics. Using behavioral measures, we tested the hypothesis that room reverberation interferes with selective attention.

Aim 2. Effects on non-spatial features. We measured whether selective attention to an ongoing target improves with time when the target has a contiguous feature distinguishing it from competing sources.

Aim 3. Role of visual cues. We explored how visual cues help direct selective auditory attention through behavioral measures and computational modeling.

Our results may benefit sailors, commanders, and war veterans, many of whom deal with complex acoustic scenes full of competing sources (where selective auditory attention is challenging in the best of circumstances), and many of whom also suffer noise-induced hearing loss that disrupts selective auditory attention.

B. Comparison between actual accomplishments and goals

Work in the first reporting period explored Aim 1. Our work on Aim 2 was very productive, and was the main focus of our efforts in years 2-4. Given the advances made in Aim 2, we reduced efforts on Aim 3; however, we undertook one auditory-visual experiment to understand how grouping influences cross-sensory integration.

C. Approach

Behavioral experiments were conducted to explore the ability of listeners to separate, understand, and identify messages from competing auditory streams. Spatial cues and other features in the acoustic signals were manipulated to explore how the continuity of the low-level acoustic information influences performance when listeners focus and maintain attention. In some experiments, multiple loudspeakers are used to present competing sounds from different locations. In other experiments, realistic spatial cues were simulated using virtual auditory space techniques. In selective attention tasks, listeners reported the identity or content of one source in the mixture. In segregation tasks, perceptual organization of the sound mixture was measured both directly and indirectly, by measuring the contributions of ambiguous sound elements to object identity and/or to object location. These methods do not deviate from those of the original proposal.

C. Accomplishments

We found that the ability to focus attention degrades as reverberant energy increases. Moreover, this degradation in selective attention is observed at levels of reverberation too low to interfere with speech intelligibility directly; the disruption is in the ability to

focus attention. This result highlights the need to minimize reflected sound energy if simultaneous sounds are likely (Aim 1)

We found that continuity of talker identity helps listeners extract information from an ongoing message. This result shows that the perceptual benefits of spatial continuity is one aspect of a more general result (Aim 2).

We found that the benefits of continuity of voice quality are not due to listeners volitionally focusing attention on the target, but are attributable to an automatic enhancement of whatever subsequent acoustic signal is similar to the acoustic signal currently in the attentional foreground. This result suggests that voice continuity effects are strongly obligatory and automatic (Aim 2).

Together, these results highlight the importance of conveying information in a single, continuous stream in order to maximize the rate of communication. For instance, when conveying information to a commander in a time of high communication volume, one should combine messages into a single continuous stream, rather than providing multiple, shorter messages (Aim 2).

We found that even when there are not competing sound streams, perceptual continuity has an influence on speech understanding. Specifically, when the talker in a sequence of digits changes from digit to digit, forcing listeners to switch attention over time from one source to another, intelligibility is degraded (Aim 2).

We found that temporal gaps in ongoing streams reduce the effects of feature continuity, but that gaps as long as 600 ms are insufficient to completely eliminate the effects (Aim 2).

We found that a well-studied auditory-visual illusion, the "flash-beep" illusion, is influenced by spatial cues. In the standard illusion, the number of perceived visual flashes is strongly influenced by the number of auditory beeps presented at roughly the same time. Here, we showed that the influence of an auditory stream on visual perception depends on the difference in the locations of the visual and auditory streams, suggesting that the flash-beep illusion reflects integration of multisensory information that is perceived as coming from a single distal source (Aim 3).

D. Productivity

Refereed articles

Schwartz A and BG Shinn-Cunningham (2013). Dynamic range compression effects spatial selection of speech sounds in normal-hearing listeners, *Journal of the Acoustical Society of America*, 133, 2329-2339.

Choi I, S Rajaram, L Varghese, and BG Shinn-Cunningham (2013). "Quantifying attentional modulation of auditory-evoked cortical responses from single-trial electroencephalography," *Frontiers in Human Neuroscience*, 7, DOI=10.3389/fnhum.2013.00115

Bizley JK, BG Shinn-Cunningham, and AKC Lee (2012). "Nothing is irrelevant in a noisy world: Sensory illusions reveal obligatory within-and across-modality integration," *Journal of Neuroscience*, 32, 13402-13410.

- Ihlefeld A, BG Shinn-Cunningham and RJ Carlyon (2012). "Comodulation masking release in speech identification with real and simulated cochlear-implant hearing," *Journal of the Acoustical Society of America*, 131, 1315-1324.
- Varghese L, E Ozmeral, V Best, and BG Shinn-Cunningham (2012). "How visual cues for when to listen aid selective auditory attention," *Journal of the Association for Research in Otolaryngology*, 13, 359-368.
- Schwartz A, J McDermott, and BG Shinn-Cunningham (2012). "Influences of ITD on segregating ambiguous sound mixtures," *Journal of the Acoustical Society of America*, 132, 357-368.
- Shinn-Cunningham BG, D Ruggles, and H Bharadwaj (2012). "How early aging and environment interact in everyday listening: From brainstem to behavior through modeling," *Proceedings of the International Symposium on Hearing*, Cambridge, UK, 23-27 July [peer-reviewed].
- Maddox R and BG Shinn-Cunningham (2011). "Influence of task-relevant and task-irrelevant feature continuity on selective auditory attention," *Journal of the Association for Research in Otolaryngology*, 13, 119-129.
- Allen K, D Alais, BG Shinn-Cunningham, and S Carlile (2011). "Masker location uncertainty in multi-talker conditions," *Journal of the Acoustical Society of America*, 130, 2043-2053.
- Schwartz E and BG Shinn-Cunningham (2010). "Dissociation of perception judgments of 'what' and 'where' in ambiguous auditory scenes," *Journal of the Acoustical Society of America*, 128, 3041-3051.
- Best, V, E Ozmeral, and BG Shinn-Cunningham (2010). "Exploring the benefit of auditory spatial continuity," *Journal of the Acoustical Society of America*, 127, 258-264.
- Mandel, M, S Bressler, BG Shinn-Cunningham, and D Ellis (2010). "Evaluating source separation algorithms in reverberant speech," *IEEE Transactions in Speech and Language Processing*, in press.

Workshops and Conferences

- Bharadwaj H, S Masud, and BG Shinn-Cunningham (2013). "Bottom-up and top-down contributions to individual differences in auditory spatial attention task performance," *Mid-Winter Meeting of the Association for Research in Otolaryngology*, Baltimore, 16-20 February [invited talk].
- Shinn-Cunningham BG (2013). "Choosing from the conversation smorgasbord of a cocktail party," *Mid-Winter Meeting of the Association for Research in Otolaryngology*, Baltimore, 16-20 February [invited Presidential Symposium talk].
- Shinn-Cunningham BG (2013). "Peripheral and central contributions to auditory attention," *Computational and Systems Neuroscience meeting*, Salt Lake City, 28 February – 2 March [invited talk].

- Shinn-Cunningham BG (2013). "The role of computational neuroscience in the science of learning," Symposium on Binaural Active Audition, Kyoto, Japan, 18 March [invited keynote talk].
- Shinn-Cunningham BG (2013). "Foundations of binaural hearing: Why does spatial hearing matter?," Annual Meeting of the Academy of Audiology, Anaheim, CA, 3 April 2013 [invited keynote talk].
- Shinn-Cunningham BG (2013). "Spatial hearing in rooms: Effects on selective auditory attention and sound localization," Neuroscience for Educators: Toward the Science of Learning, Boston, MA, 19 April 2013 [invited talk].
- Shinn-Cunningham BG (2013). "Auditory attention (or how you hear a voice inside your head)," Eastern Auditory Retreat, University of Maryland, 15 June [invited talk].
- Bressler S, V Lim, D Aksyonova, and BG Shinn-Cunningham (2012). "Cortical and brainstem differentiation of neural responses to hits versus misses," Journal of the Acoustical Society of America, 3388
- Shinn-Cunningham BG (2013). "Individual differences in the ability to direct auditory attention," Behavioral and Cognitive Neuroscience Seminar, Columbia University, 29 November [invited talk].
- Shinn-Cunningham BG (2012). "Spatial hearing: Why having two ears matters in everyday settings," Annual Meeting of the American Auditory Society, Scottsdale, AZ, 8-10 March [invited talk].
- Shinn-Cunningham BG (2012). "Analyzing objects through time," Journal of the Acoustical Society of America [invited talk].
- Shinn-Cunningham BG (2012). "The importance of perceptual continuity in focusing auditory attention," MRC Cambridge, UK, 11 April [invited presentation].
- Shinn-Cunningham BG (2012) "The importance of perceptual continuity in focusing auditory attention," MRC Cambridge, UK, 11 April
- Shinn-Cunningham BG (2011). "Attention to perceptually continuous auditory streams," 1st International Conference on Cognitive Hearing Science for Communication, Linköping, Sweden, 19-22 June [invited talk].
- Ruggles D and BG Shinn-Cunningham (2011). "Bottom-up contributions to spatial selective auditory attention in normal-hearing listeners," 1st International Conference on Cognitive Hearing Science for Communication, Linköping, Sweden, 19-22 June.
- Shinn-Cunningham, BG. (2011). "Understanding auditory attention: Relating perception to network activity," Woods Hole Workshop on Computational Neuroscience at the Telluride Neuromorphic Cognition Engineering Workshop, Telluride CO, 4-8 July [invited talk].
- Varghese LA, V Best, and BG Shinn-Cunningham (2011). "Converging evidence from behavior and electroencephalography for differences in the storage of streams versus individual sound objects," Journal of the Acoustical Society of America, 130, 2517.

- Bizley J, BG Shinn-Cunningham, and AKC Lee (2011). "Intra- and inter-modal spatial attention: a case of counting flashes 'n beeps," Mid-Winter Meeting Assoc Res Otolaryng, Anaheim, CA.
- Shinn-Cunningham, BG (2011). "Dynamics of focusing and switching auditory attention," Ann Interdiscip Conf, Jackson Hole, WY.
- Shinn-Cunningham, BG (2011). "Segregating and selecting auditory objects," Mid-Winter Meeting Assoc Res Otolaryng, Anaheim, CA.
- Shinn-Cunningham, BG (2011). "Designing to human perceptual constraints in command and control displays," NUWC, Newport, RI.
- Shinn-Cunningham, BG (2011). "Focusing, maintaining, and switching attention," J Acoust Soc Am, 127, 2029.
- Shinn-Cunningham, BG (2011). "Attention to perceptually continuous auditory streams," 1st Int Conf Cogn Hear Sci, Linköping, Sweden.
- Shinn-Cunningham, BG (2010). "Segregating and selecting auditory objects," Mid-Winter Meeting of the Association for Research in Otolaryngology, Anaheim, CA, 6-10 February
- Schwartz, A, J McDermott, and BG Shinn-Cunningham (2010). "Influences of interaural time differences in grouping of ambiguous Auditory scenes," Mid-Winter Meeting of the Association for Research in Otolaryngology, Anaheim, CA, 6-10 February
- Bressler, S, S Masud, V Best, and BG Shinn-Cunningham (2010). "Influence of voice continuity on selective auditory attention," Mid-Winter Meeting of the Association for Research in Otolaryngology, Anaheim, CA, 6-10 February
- Neilans, EG, TE Welch, R Maddox, BG Shinn-Cunningham, and M Dent (2010). "Are all syllables perceived equally? A comparative analysis of song syllable perception in zebra finches (*Taeniopygia Guttata*) and budgerigars (*Melopsittacus Undulatus*)," Mid-Winter Meeting of the Association for Research in Otolaryngology, Anaheim, CA, 6-10 February
- Garcia, KA, TE Welch, S Rajaram, K Sen, BG Shinn-Cunningham, and ML Dent (2010). "Acoustic Factors Influencing Auditory Streaming in Budgerigars and Zebra Finches," Mid-Winter Meeting of the Association for Research in Otolaryngology, Anaheim, CA, 6-10 February
- Shinn-Cunningham, BG (2010). "Focusing, maintaining, and switching attention," Journal of the Acoustical Society of America [invited]
- Shinn-Cunningham, BG (2010). "How reverberation degrades and aids source perception in auditory scenes," Journal of the Acoustical Society of America [invited]
- Shinn-Cunningham BG (2010). "Mechanisms of auditory attention," Gordon Conference on the Auditory System, New London, NH, 13-18 June [invited]
- Shinn-Cunningham, BG (2010). "Top-down influences on auditory perception," Eaton-Peabody Laboratory, Massachusetts Eye and Ear Infirmary, Boston, 26 February [invited]

Shinn-Cunningham, BG (2010). "Oscillations in auditory attention," Cognitive Rhythms Collaborative, Massachusetts Institute of Technology, Boston, 28 June [invited]

Ruggles, D and BG Shinn-Cunningham (2010). "Reverberation disrupts spatial selective auditory attention," Mid-Winter Meeting of the Association for Research in Otolaryngology, Anaheim, CA, 6-10 February

Awards and Honors

Founding Director, Center for Computational Neuroscience and Neural Technology, 2011-

PI and Director, CELEST NSF Science of Learning Center, 2012-

Vice President Elect / Vice President / Immediate Past Vice President, Acoustical Society of America, 2013-2016

Executive Council, Acoustical Society of America, 2010- 2013

Executive Steering Committee, Hariri Institute for Computational Science and Engineering, 2011-

Mentorship Award, awarded by the Student Council of the Acoustical Society of America, 2013

Provost's Senior Hiring Initiative Committee, 2012-

Associate Provost's Administrative Strategy Group, 2012-2013

College of Fellows Steering Committee, Acoustical Society of America, 2010-2012

Chair, Internal Affairs Council, Acoustical Society of America, 2013

Audit Committee, Acoustical Society of America, 2010- 2013

Student Council Advisor, Acoustical Society of America, 2011-2013

External Advisory Committee, MGH/Harvard/MIT Advanced Multimodal Neuroimaging Training Program, 2012-2013

Director Search Committee, Medical Research Council Institute of Hearing Research, Nottingham, UK, 2013

National Academies Panel on Human Factors Science at the Army Research Laboratory, 2013-2014

Presidential Symposium Speaker, Mid-Winter Meeting of the Association for Research in Otolaryngology, February 2013

Keynote Speaker, Binaural Active Audition Symposium, Kyoto Japan, March 2013

Keynote Speaker, Annual Meeting of the Academy of Audiology, Anaheim, CA, April 2013

National Academies of Science Soldier Systems Panel, 2011-2012

Appointed Member, Advisory Panel, Hearing Fitness for Duty initiative (DoD), 2011-2-12

MRC Institute of Hearing Research Review Subcommittee, 2011-2012

External Advisory Committee, MGH/Harvard/MIT Advanced Multimodal Neuroimaging Training Program, 2012

Chair of the AUD study section for the National Institutes of Health.

J. Award Participants

PI: Barbara Shinn-Cunningham

Research Staff: Scott Bressler, Salwa Masud, Nathaniel Durlach